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Two-Phase Flow Pattern of Air-Water with Low Viscosity in a 5-Degree Slope of a Capillary Pipe

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ABSTRACT

The main objective of this research is to find new information related to the characteristics of air-water two-phase flow patterns with low viscosity. In addition, this study also wants to prove that whether the pipe slope of 5 degrees affects the characteristics of the flow pattern map that occurs. The research was carried out using experimental methods, with an inner pipe diameter of 1.6 mm and a length of 130 mm. The test section with a slope of 5 degrees against the horizontal position. The working fluid being used was gas (air) and water mixed with glycerine at concentrations of 0%, 10%, 20%, 30% for each blend, and varying the superficial water and gas velocity in the range of J_L = 0.033 to 4.935 m/s and J_G = 0.025 to 66.3 m/s. The research was done by the method of visualization using a high-speed camera. The study found new five types of characteristics of flow pattern regarding bubbly, plug, slug annular, annular and churn. It was also found that the plug flow pattern dominates the result in this study, viscosity changes effect to be seen on the bubbly and plug flows as well as on the transition flow pattern. Flow patterns formed later are mapped based on superficial velocity variation. The map of the flow pattern is also compared to the results of previous research, and it has resulted in conformity.

Keywords:
Characteristics; pattern; superficial velocity; two-phase flow; viscosity

1. Introduction

Two-phase flow is commonly applied in oil and gas piping systems, cooling electronic devices, nuclear reactors, geothermal. Besides, in the biomedical sector, it can be found especially in the cardiovascular system. In recognizing this flow, it is usually used two components that have different chemical substances such as steam-water, air-water or the mixture of water and glycerine. The two-phase flow can be classified based on the types of streamflow position, flow direction, channel size, and shape. The most important thing to learn from both single- and two-phase flows is the flow pattern. The flow pattern and flow pattern map become a critical point in the case study of two-phase flow, for example, the liquid-gas phase. The mixture of liquid-gas contains a lot of relations required for a two-phase conservation equation that depends on how far the flow pattern identification can be made.

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The previous researcher carried out the study on two-phase flow generally discussing conventional two-phase flow. Chung and Kawaji [1] identified the phenomenon that differentiates the mini channel and microchannel. The research was done by using nitrogen gas and water in a channel with a diameter of 530, 250, 100 and 50 µm. In the pipe with a diameter of 530µm and 250µm, the characteristic of two-phase flow (flow pattern map, void fraction, pressure drop) is similar to the aspects of the flow in a mini channel. In the pipe with a diameter of 100 and 50µm, flow characteristics deviate from the characteristics of the mini channel, which is the dominance of the slug flow. The bubbly, churn, slug-annular flow occurred in the channel of DH ≤ 100 µm because the viscosity and surface tension is increasing. Therefore, it is clear that at the pipe diameter interval investigated, the diameter influences the characteristics of the two-phase flow. To know the characteristic of slug, bubbly, churn, annular and slug-annular flow, the flow can be analyzed by using a visualization method, i.e., by using the high-speed camera. This method depends on the analysis of the figure and uses some steps to obtain the required data. One of the advantages of this method is the possibility to analyze the air in a significant amount by increasing a higher accuracy and avoiding destroying or disturbing the streamflow. From the description mentioned before, the research on flow patterns is limited.

Fukano *et al.,* [2] conducted a study of two-phase flow in a mini channel and microchannel by ignoring gravity considered has no significant effect on the flow. The occurred flow pattern is only affected by viscosity, superficial liquid-gas velocity, and liquid surface tension. The flow pattern map obtained in the mini pipe and micropipe will be different from the flow pattern and map in the conventional pipe. The flow pattern and map become the crucial parameter to show the characteristic of two-phase flow.

Kawahara *et al.,* [3] studied nitrogen-water two-phase flow which is ionized by using the circulation with a diameter of 100µm made of fused silica and the superficial gas velocity of 0.1-60 m/s and superficial water velocity of 0.2-4 m/s. The obtained data was analyzed by using a method in addition to the visualization method of Kawahara et.al (2002), i.e., probability method. This is because, in a predetermined flow condition, several flow patterns appear alternately at low water flow rates. From this research, it can be identified five main patterns, i.e., the flow of gas core with a smooth-thin liquid film, liquid alone (liquid slug), the flow of gas core with a smooth-thick liquid film, flow of gas core with a ring-shaped liquid film, and flow of gas core with the deformed interface.

Sur, A. *et al.,* [4] have found the influence of dimensions, and superficial velocity on two-phase flow patterns and pressure drop on air-water mixture flow in microchannels. They found a flow of bubbles, slug, and annular. The two-phase friction pressure gradient is also measured and the data are compared with predictions from a separate flow model, a homogeneous flow model, and the results show that the flow pattern-based model provides the best prediction of a two-phase pressure drop in the microchannel.

Correlation of two-phase friction pressure reduction and a void fraction has been investigated in mini channels based on separate flow models and drift flux models. It was found the main parameters (Laplace non-dimensional constants) to correlate Chisholm parameters and distribution parameters [5]. Previous research has carried out experimental studies of flow patterns, void fractions, and pressure drop of two-phase gas-liquid flow from CO_2 and MEA/[Bmim] [BF4] water solutions in 400 µm square microchannel. Three types of flow regimes were found, namely, slug-bubbly flow, slug flow, and slug-annular flow. The void fraction and the pressure drop in the slug flow regime were investigated without consideration of mass transfer. Considering the effects of chemical absorption, two correlations were proposed with Hatta numbers to predict the two-phase void fraction and the Chisholm C parameter, which showed good predictive performance [6]. Previous research also provided a comprehensive evaluation of experimental data used to produce gas-liquid flow maps in vertical pipes. The critical review also created a critical analysis of measurement techniques used to identify bubbles, slugs, churn, and annular [7]. Review deals with the analysis of the factors that influence the boundaries of the two-phase regime in different cross-channel channels, whose minimum size is smaller than the capillary constant have been studied. This study analyzes the main factors that influence the structure of the two-phase flow, such as gas and liquid flow rates, channel parameters and input sections, surface wetting in the channel, liquid properties, and gravity. It results that the development of two-phase flow instability has a significant impact on the formation, evolution, and change of flow regimes [8]. The previous paper analyzed the phenomenon of liquid carryover at the T-junction using the Volume Faction with the k-ε turbulence model. The efficiency of T-junction separation was measured through the fraction of air and water mass flow rates between branches and primary arms in the range of diameter ratios of 0.6 to 1.0, surface water velocity of 0.186 to 0.558 m / s, and air-surface velocity of 4 to 8 m/s. The results showed that the simulation model has been successfully validated with an average deviation of less than 5% and can be used to predict the phase separation of the slug flow at the T-junction. Numerical models confirm the significant influence of diameter ratio and superficial velocity of air and water on phase separation. In the slug flow regime, the performance of the T-junction can be improved by reducing air velocity or increasing water velocity [9]. Previous articles have also analyzed the two-phase turbulent flow of crude oil and sand in choke valves using 3D computational fluid dynamics simulations. The parameters considered are the percentage of valve opening, sand flow rate, and the pressure difference between the inlet pipe and the outlet. It was found that high erosion rates for opening small valves and opening large valves [10]. Research has previously used a new modification of the schlieren and laser-induced fluorescence method to examine fluid-gas motions in the microchannel for obtaining data on fluid distribution to detect the presence of film, drops, and liquid jets in the walls of the channel gap [11]. Meanwhile, Computational Fluid dynamics two-phase flow has recently been carried out using annular pipes (inner diameter of 12.7 mm and an outer diameter of 38.1 mm, length of 16 m) using the Volume of Fluid model and considering the effect of k-e turbulence. The simulation uses variations in the gas superficial velocity, and maintains a fixed liquid superficial velocity, and has succeeded in identifying flow regimes including the size and shape of bubbles, slugs, and zigzag phenomena and fusion. This flow regime is clearly influenced by air velocity [12]. An experimental study has also been carried out using a conductance probe sensor in a water-air horizontal annular flow (diameter pipe of 26 mm, gas superficial velocity of 10 to 40 m/s and liquid superficial velocity of 0.025 to 0.4 m/s). The results showed that the decrease in liquid holdup was obtained by increasing the superficial gas velocity and decreasing the superficial fluid velocity or vice versa [13].

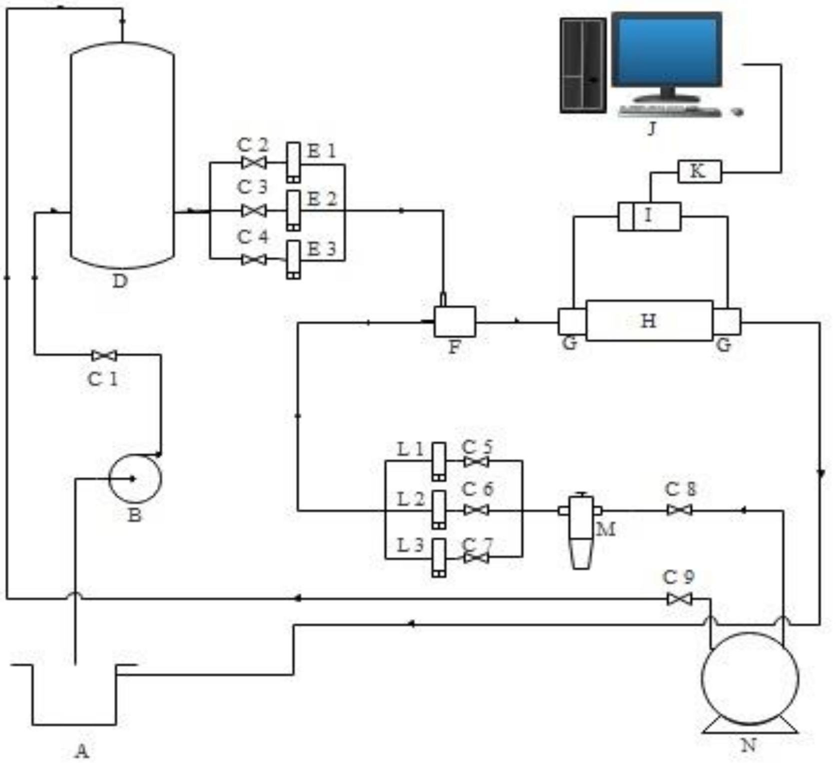
Based on the studies mentioned above, it can be concluded that the application of two-phase flow is broad, and also quite a lot of previous research has been done. However, as far as the author's knowledge, insufficient research is carried out on capillary pipes with horizontal or sloping pipe positions. Though this problem will be challenging that arises in this domain in the future. Therefore, this paper presents the result of a two-phase flow investigation on air-water with low viscosity in a capillary pipe with a slope of 5° toward horizontal.

2. Methodology

The installation of equipment in this research can be seen in figure 1. The installment consists of primary components, i.e., water tanks, water pumps, air compressors, pressure vessels, the test section was made from a glass pipe with an inner diameter of 1.6 mm and length of 130 mm, water traps, mixers, and connectors. The additional equipment in this research is a “valydine” differential pressure transducer, an optical correction box, a camera, and a computer. The measurement tools are water flowmeter, air flowmeter. For streaming video shooting to determine the flow pattern, a Nikon type J4 high-speed camera with a speed of 1200 fps and a resolution of 640 x 480 pixels was used. This research was carried out in an adiabatic state in the sense that there was no heat exchange during the process. That is done at the same temperature of 27°C air and water both in and out. The working fluid being used was gas (air) and water mixed with glycerine at concentrations of 0%, 10%, 20%, 30% for each blend. Properties of the working fluid can be seen in table 1.

Table 1
Properties of working fluid

Fluid	Specific Gravity	Kinematic Viscosity [mm²/s]	Surface Tension [mN/m]	Code
Gas+0% glycerine	1.0021	0.842	71.03	GL0
Gas+10% glycerine	1.0358	1.331	67.96	GL10
Gas+20% glycerine	1.0619	2.315	61.56	GL20
Gas+30% glycerine	1.0839	2.361	60.86	GL30



A. Water Tank
B. Water Pump
C. Valve
D. Pressure Tank
E. Liquid Flowmeter
F. Mixer
G. Flange
H. Test Section
I. Pressure Transducer
J. Personal Computer
K. Data Acquisition
L. Air Flowmeter
M. Watertrap
N. Compressor

Fig. 1. Schematic diagram of experimental apparatus

3. Results and Discussion

The typical two-phase flow pattern produced by the high-speed camera was shown figure 2. The experiment was carried out at the interval of superficial gas velocity (J_G) of 0.025 – 66.3 m/s and the superficial liquid velocity (J_L) of 0.033 – 4.935 m/s. The research result of a two-phase flow pattern map with the mixture of glycerine in the range of 0%, 10%, 20% and 30% in a pipe with an inner diameter of 1.6 mm with a slope of 5° as shown figure 3 – 6.

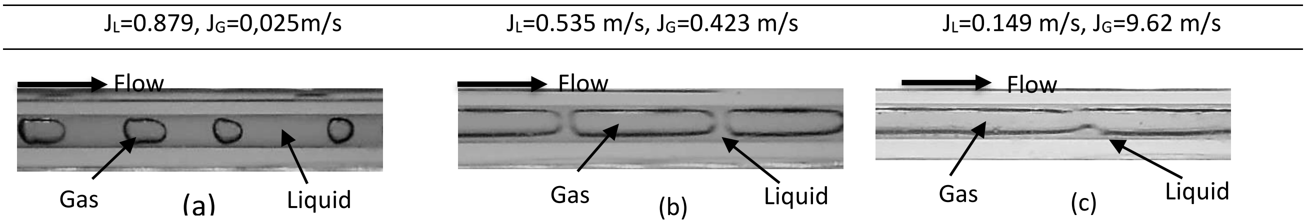


Fig. 2. A typical two-phase flow pattern based on J_L and J_G variations, (a) Bubble, (b). Plug, (c). Slug annular/Annular

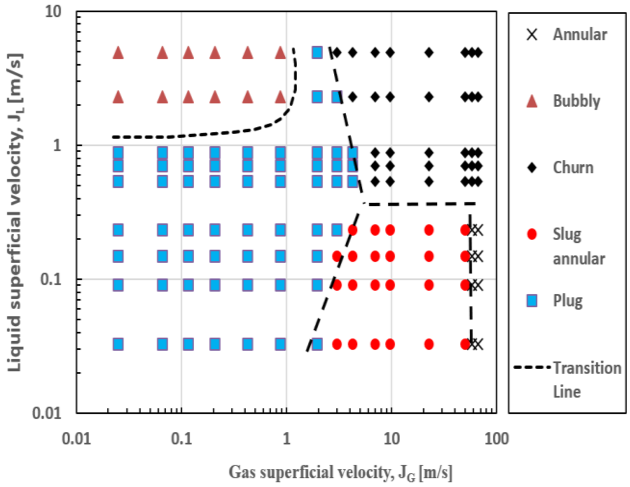


Fig. 3. Map of 0% glycerine flow pattern

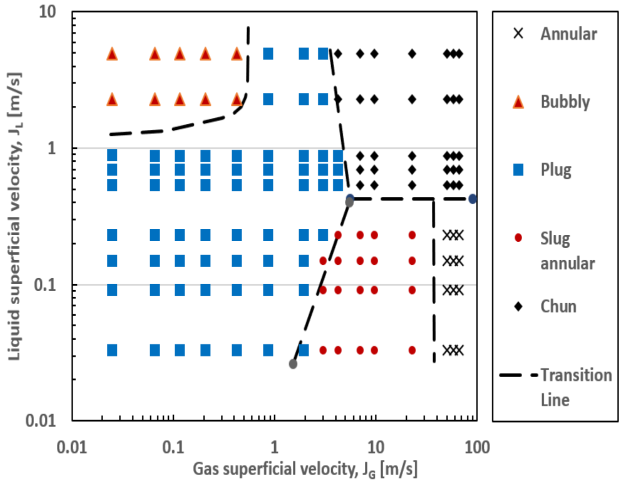


Fig. 4. Map of 10% glycerine flow pattern

Flow patterns that have been justified by the high-speed camera are then mapped based on variations in the superficial velocity. On the map of the flow pattern, the abscissa shows the superficial velocity of the gas (J_G) with a minimum value of 0.01 and a maximum value of 100, while the ordinate is the superficial velocity of the liquid (J_L) with a minimum value of 0.01 and a maximum value of 10. On the map of flow patterns that have been obtained, there are also transition lines between patterns in which this transition line shows which coordinates flow changes between one flow pattern and the others.

The increase of viscosity against the distributed flow pattern in the flow pattern map shows the difference of the transition line area that occurs between each flow pattern map with different glycerine concentrations (Figure 3 – 6). The comparison of flow pattern map is 0%, 10%, 20%, 30%. The area of transition of the occurrence of bubbly is at the glycerine concentration of 0% which is wider than those of other concentrations, i.e., 10% and 20%.. However, these results are also still almost as large as the results at a concentration of 30% glycerine. A significant difference is in the transition to the appearance of churn flow at concentrations of 0% and 10% which have different flow patterns. The number of bubble flow patterns at 10% glycerine concentration was lower than at 0% glycerine concentration, and for JL> 1 m / s and JG> 0.9 it turned out that there were more plug flow patterns. Meanwhile, at 30% glycerine concentration, the annular transition line tends to shift toward the annular slug. so it can be concluded that an increase in viscosity will provide an opportunity for the emergence of the annular or annular two-phase flow pattern.

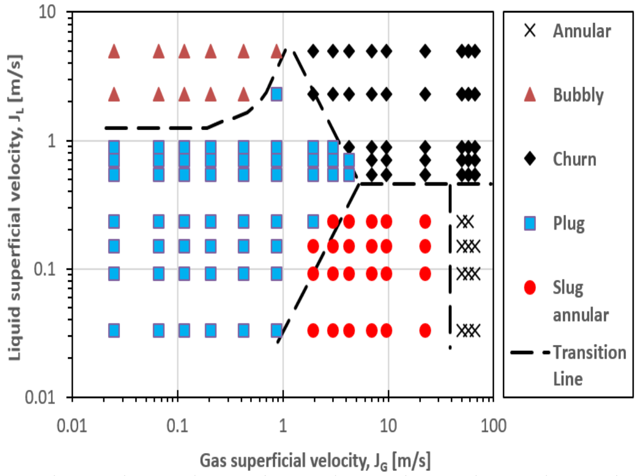


Fig. 5. Map of 20% glycerine flow pattern

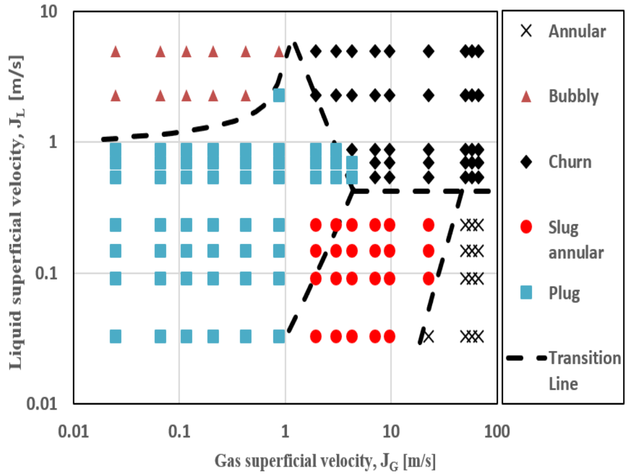


Fig. 6. Map of 30% glycerine flow pattern

Meanwhile, Noverdi *et al.,* [14] conducted research on two-phase flow which using a pipe with a diameter of 1.6 mm and set in a horizontal position. The working fluid used in this research was air as the gas phase and water as the liquid phase. The mixture of water and glycerine was also used in this research to know the effect of glycerine against the formation of a two-phase flow pattern. The flow pattern map in this research was determined by using the parameter of the superficial velocity. The value of superficial gas velocity was ranged on 0.008 – 64.42 m/s and the other superficial velocity was ranged on 0.002 – 3.09 m/s. The observed flow pattern was bubbly, plug, slug annular, churn, wavy annular an annular flow pattern. The comparison between present research and Sudarja et.al. can be shown in Figure 7.

On the other hand, Triplett *et al.,* [15] studied two-phase flow in a mini pipe with a diameter of 1.097 and 1.45 mm. The used media is liquid (water) fluid and air (gas) fluid. The superficial velocity of gas and liquid is carried out in a varying amount in order to obtain some types of data. The variation of the superficial gas velocity being used ranged from 0.02 m/s to 80 m/s. At the same time, the superficial liquid velocity ranged from 0.02 m/s to 8m/s. The flow pattern that successfully observed during research was bubbly, slug, churn, slug-annular, and annular. All those flows occurred in all of the pipe types that are used, i.e., a circular pipe with a diameter of 1.097 mm and semi-triangular pipe with a diameter of 1.45 mm. The comparison between present research and Triplett et.al. can be shown in Figure 8. Meanwhile, Santoso *et al.,* [16] studied the plug and slug air-water two-phase flow pattern and its parameters (unit cell speed, unit cell length, slug frequency, and bubble speed). The measurement of parameters in the slug and plug flow pattern was done by using a high-speed video camera. The research was done in the superficial water velocity range on 0.14 m/s – 1.95 m/s and the superficial air velocity range on 0.52 m/s – 3.65 m/s. The research was carried out in the horizontal pipe with a diameter of 24 mm. The resulted flow pattern was plug, slug and transition flow pattern. Meanwhile, Manop Pipathattakul [17] performed an experimental study to examine the effects of gap size on the flow pattern maps of air-water two-phase flow inside a mini-gap annular channel with inclination angles (h) of 0°, 30°, and 60°.

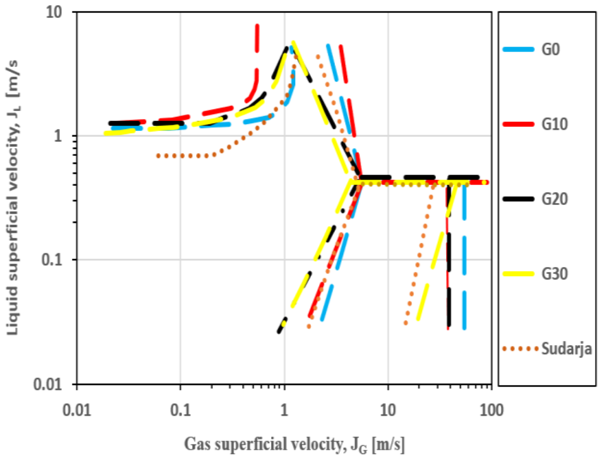


Fig. 7. Comparison between present result flow pattern maps and Sudarja *et al.,* (2014)

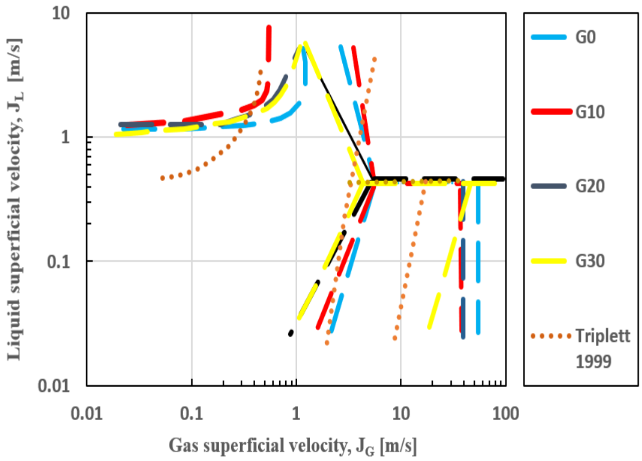


Fig. 8. Comparison between present result flow pattern maps and Triplett *et al.,* (1999)

The experimental conclusions, the angle of inclination and the various gap sizes are influential in the transition of flow regimes. On the other hand, A. Korawan *et al.,* [18] found a two-phase flow pattern change in the horizontal pipe with variations in surface water velocity. The testing module uses acrylic with a diameter of 36 mm. Working fluid used was water and air. The variation in surface water velocity is 0.4-1.0 m / s and the volumetric ratio is 0.05. The results showed that there was a change in flow patterns throughout the module test, i.e. the greater the water velocity, the flow patterns would change from bubble flow to slug flow. Comprehensive visualization of two-phase air-water flow in a mini vertical pipe has been carried out. Different flow patterns of air-water flow are observed simultaneously in mini-pipes at different values of air and water flow rates. As a result, a flow pattern map is obtained for flow in a mini pipe, with respect to the low-velocity liquid and gas phases [19]. Previous studies have also shown clearly that the superficial velocity of liquids and gases and viscosity significantly influence the pressure gradient, where the pressure gradient is very influential on the flow pattern [20]. An experimental study on the adiabatic flow pattern of two-phase gas-liquid flow in a horizontally oriented mini-channel was carried out. The test part is a glass pipe with an inner diameter of 1.6 mm. The range of shallow speeds of gases and liquids is 0.025 - 66.3 m / s and 0.033 - 4.935 m / s, respectively. The working liquid is an aqueous solution of air and glycerol aqua with low viscosity, which is 0%, 20%, 40%, and 60%. The result, found bubbly, plug, slug-annular, annular, and churn, while multilevel flow does not appear. Changes in liquid viscosity affect the shifting of transition lines between flow patterns, specifically slug-annular to annular and slug-annular, and annular to churn flow [21]. On the other hand, previous researchers have also presented results in predicting multiphase flow patterns and their effect on flow measurements in vertical pipes. This research was carried out using well and reservoir properties with dynamic OLGA simulator equipment to predict multi-phase flow patterns in vertical pipes (35 oil wells, pipe diameter 3.5 inches). The prediction of the oil flow rate from the 35 oil wells is compared with the measured flow rate and a good fit is obtained. In addition, the simulation results also show the model's performance expectations and the magnitude of variations that might occur in the oil flow rate measured by different methods. The simulations and results also show the performance of the model as expected and its usefulness in explaining the implications of local flow patterns on oil flow rates measurement and expanding the application of computational fluid dynamics of flow patterns on vertical pipes [22].

4. Conclusions

This research makes a significant contribution in terms of finding new characteristics of bubbly, plug, annular slug, churn, and annular flow patterns. These characteristics are especially associated with an increase in the viscosity of glycerine concentration in water which affects the annular-annular plug-slug transition area in mini channel. The annular flow transition line and the annular slug tend to shift toward the plug for the smaller J_G and the J_L is relatively fixed. Meanwhile, the churn transition line tends to shift toward the plug if the J_G gets smaller for a constant J_L. The slope of the pipe of 5^o apparently did not provide a too significant difference to the two-phase flow characteristics. The results of the flow map maps of this study have been compared with previous studies and they show corresponding results including the slopes of 0^o [21] and 5^o.

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